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CALCULATIONS FOR USE WITH THE FAST NEUTRON METER

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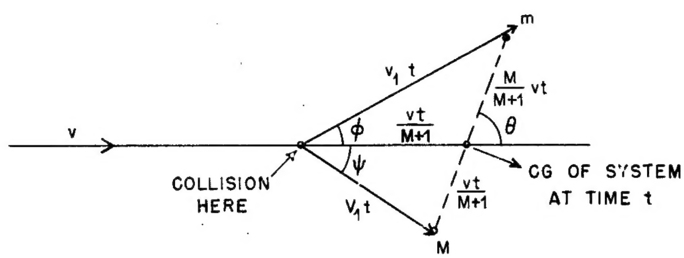
TOLERANCE DOSE

In order to make the necessary calculations on tolerance dose and to determine the calibration of the neutron meters, the information given here is necessary. The energy of the neutrons, the composition of tissue and of gases in the ionization chambers, the cross sections of the various atoms involved, and the fraction of energy lost per collision must be known.

The energy lost per collision can be obtained by the following simple calculation. Assume that a neutron of mass m = 1 and velocity v strikes a stationary atom of mass M, after the collision the neutron will have a velocity v, at the angle ϕ with original direction, the atom M will have a velocity V, at an angle ψ with the original direction of the neutron. The line connecting the two particles and passing through the center of gravity will have turned through an angle θ . At some time t after the collision the particles would have the positions shown in the following sketch, if energy is conserved.



Now - $$v_1^2 = \frac{v^2}{(M+1)^2} \ (1 + M^2 + 2M \cos\theta)$$

assuming that θ varies isotropically then the average loss of energy in a collision is

$$E(\text{lost}) = \left(\frac{v^2 - v_1^2}{2}\right) = \frac{v^2}{2\pi} \int_0^{\pi} \left[1 - \frac{1}{(M+1)^2} \ (1 + M^2 + 2M \cos\theta)\right] d\theta$$

so that -
$$E(\text{lost}) = \frac{v^2}{2} \cdot \frac{2M}{(M+1)^2} = E \frac{2M}{(M+1)^2}$$

Using this relation and taking cross sections from data included in Ibser's tables (Chicago Report No. 334) and assuming the composition of tissue to be that given in the table, we have the necessary data in a useful form.

Atom species	% by wt	Atoms g σ	Average energy loss per collision f	σ x 10^{24} cm² .5 Mev	1 Mev	2 Mev	4 Mev
H	10	6.02×10^{22}	.500	5.5	4.2	2.85	1.7
C	12	6.02×10^{21}	.151	3.5	2.5	1.7	1.6
N	4	1.71×10^{21}	.124	3.5	2.5	1.4	1.6
O	73	2.74×10^{22}	.111	3.5	2.0	1.2	1.8

The energy absorbed per gram of tissue irradiated with neutrons can be expressed as

$$E = 1.602 \times 10^{-12}\ EN \sum_i \sigma_i f_i Q_i$$

where N is number of neutrons incident per cm²
E is energy of neutrons in ev
σ_i is cross section in cm² of i'th kind of atom
Q_i is number of i'th kind of atom
f_i is average loss of energy per collision with i'th kind of atom.
1.602×10^{-12} is conversion factor $\frac{\text{ergs}}{\text{ev}}$

If one rep (roentgen equivalent physical) is that amount of radiation which will lose 83 ergs per gm of tissue, then the number of neutrons per cm² to give one rep will be given by

$$N = \frac{83}{1.602 \times 10^{-12}\ E\ \Sigma_i \sigma_i f_i Q_i}$$

Taking tolerance for neutrons as .02 rep following table can be formed.

Energy in Mev	$\frac{N}{cm^2}$ per .02 rep	$\frac{N}{cm^2}$ for $\frac{.02 \text{ rep}}{8 \text{ hr}}$
.5	11.50×10^6	400
1.0	7.66×10^6	266
2.0	5.68×10^6	197
4.0	4.44×10^6	156

CALIBRATION OF NEUTRON METER

The chambers in use for measuring fast neutrons are mounted on boxes which contain Lindemann electrometer systems. The Lindemann is a very sensitive and rugged instrument which can be operated easily at sensitivities of 200 div/volt. Since the sensitivity can be changed easily, the calculations will be made in terms of volts per sec rather than in divisions per sec and they will then hold at all sensitivities.

The units as used here provide two calibration voltages of -0.1 volts and -0.5 volts.

The circuit is usually arranged so that the fiber moves to the right when these voltages are applied. The fiber is usually located in the center of the scale when there is no charge on it so that either positive or negative ionization currents may be measured without changing the instrument.

Two chambers are used, one filled with argon (or other non-neutron sensitive gas), the other with methane or some other hydrogenous gas (to provide recoil proton). They are adjusted by changing the pressures until the ionization currents in each are equal when subjected to the same amount of gamma radiation.

In case the two chambers are used at the same time on the same Lindemann (double chamber method) they are balanced so that there is no resulting current, opposite voltages being applied to each chamber so that their ionization currents will cancel. In this case then, when neutrons and gammas both hit the two chambers, there will be an excess of current in the methane chamber which will show on the Lindemann. If the chambers are used separately, the rates of the two must be determined separately and the difference taken to determine the rate due to the neutrons alone.

To calibrate the chambers the following calculations are used.

1 "r" of gammas = 83 ergs/g of tissue

1 "rep" of neutrons = 83 ergs/g of tissue (definition)

$$1 \text{ ``rep'' of 1 Mev neutrons} = \frac{83 \sum_{\text{methane}} \sigma_i f_i Q_i}{\sum_{\text{tissue}} \sigma_i f_i Q_i} = 202 \text{ ergs/g methane}$$

$$1 \text{ ``r'' gammas gives} = \frac{83 \times \text{electrons per g of methane}}{\text{electrons per g of air or tissue}}$$

$$= \frac{83 \times 10/16 \times 6.02 \times 10^{23}}{14.4/28.8 \times 6.02 \times 10^{23}} = 104 \text{ ergs/g methane}$$

for a tolerance rate of .02 rep/8 hr the number of volts/sec due to neutrons

$$Rn = \frac{1}{5} R\gamma \times \frac{202}{104} = .39\, R\gamma$$

allowing a 5% correction for the wall effect

$$Rn = .37\, R\gamma$$

for tolerance amounts.

The tolerance rates of course depend on the pressures used and must be determined for each pressure used.

If the chambers are both to be used at the same time they are calibrated for gammas using the same kind of voltage on each, then the tolerance rate for neutrons is .185 R_γ when the chambers are used with opposite voltage.

When the chambers are filled with 50 lb/in^2 above atmospheric pressure of methane and about 27 lb/in^2 above atmospheric pressure of argon then about -440 volts is applied to the methane chamber and + 440 volts is applied to the argon chamber. The sensitivity for neutrons in this case is then about .08 volt/sec for a tolerance rate.

Similar calculations could be carried out for other gases. The effect of neutrons on the argon is neglected here because (1) a very small amount of energy can be transferred per collision and the cross section is probably very small so that there would be relatively few collisions.